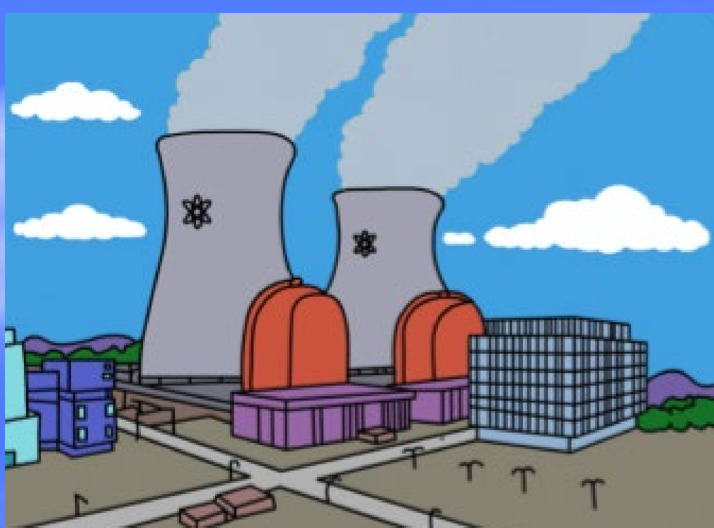
Nuclear Energy and Mass Defect

Lesson 5



Objectives

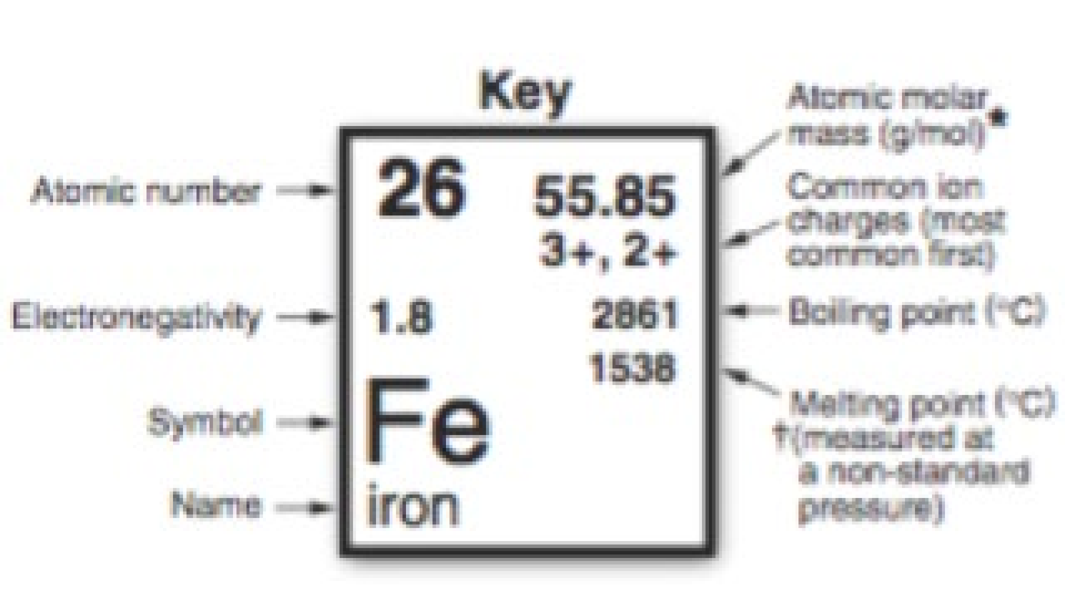
- use the law of conservation of charge and mass number to predict the particles emitted by a nucleus.
- relate, qualitatively and quantitatively, the mass defect of the nucleus to the energy released in nuclear reactions, using Einstein's concept of mass energy equivalence.

Question!

- What is an alpha particle and why is it important?
- What other name might it go by?

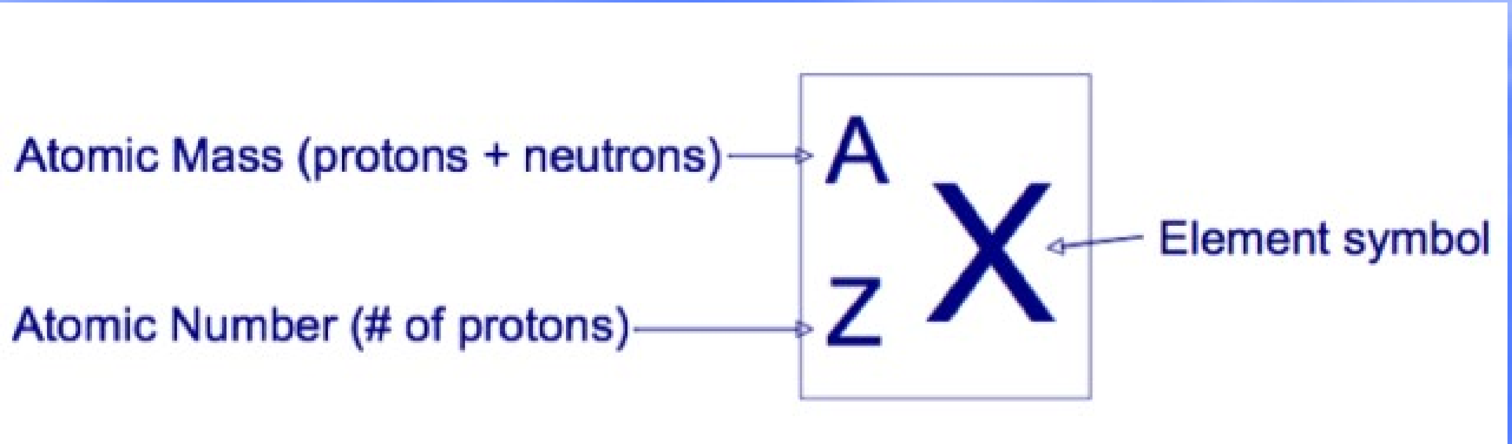
Review of Atoms

- There are presently 117 elements known to science (as of 2008). Many of these elements (1-94, except 43 and 61) occur in nature, while others are produced synthetically in a lab.
- Protons are located in the nucleus of the atom, have a positive charge.
- The number of protons determines the type of element.
- The number of protons an element has is referred to as the element's atomic number.



Atomic Mass

- All particles (p^+, e^-, n^0) make up the atom's mass. But because the mass of an electron is so small compared to that of a proton (about 1/2000th), we ignore it.
- Therefore, to determine the mass of an atom, add the number of protons and neutrons.
- protons (Z) + neutrons = atomic mass (A)



Examples

- The symbol for fluorine is $^{19}_{9}F$
- Calculate the number of protons, neutrons and mass of the fluorine atom.
- Now carbon-12 $^{12}_{6}C$
- How about carbon-14 $^{14}_{6}C$
- Note: the protons and neutrons are collectively called nucleons.

Atomic Mass Units

- Dealing with numbers such as 9.11×10^{-31} kg is a little cumbersome.
- For this reason, scientists that work with the nucleus deal in terms of atomic mass units (u). These are defined as exactly 1/12 of the mass of carbon-12
- $1u = 1.66x10^{-27}$ kg= 931.5 MeV/c^2
- See your data table for mass of the electron in MeV/c^2

Isotopes

- Elements can have atoms that contain the same number of protons but have different masses. The difference is due to the different number of neutrons in the nucleus. These are called isotopes.
- One example is carbon. It has three main isotopes: carbon-12, -13, and -14

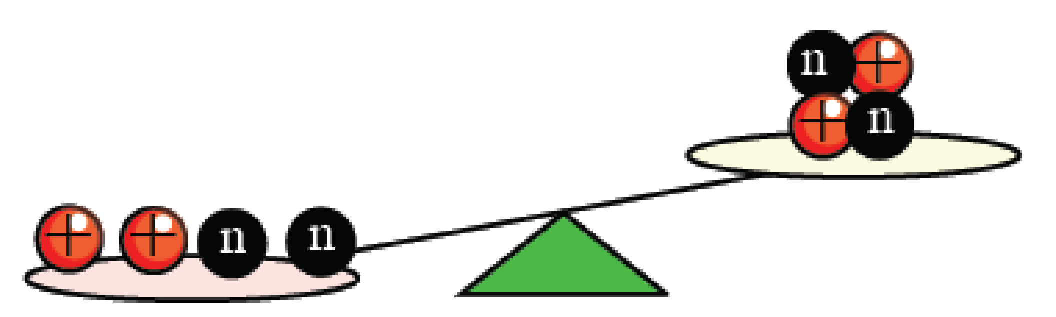
Nuclear Physics:

- a branch of physics dealing with the nucleus of the atom
- the nucleus is made up of protons and neutrons
- collectively, these particles are called nucleons

English physicist James Chadwick confirmed the existence of neutrons in 1932 (Nobel Prize in 1935).

A Problem Arises…

- **Around the time physicists started breaking nuclei into their constituent parts, an interesting problem started to present itself:**



- **The mass of a nucleus (like helium-4, shown here) is slightly LESS than that of its individual parts: two neutrons and two protons.**

The answer came from Einstein's theory of Special Relativity and the mass-energy equivalence eqn:

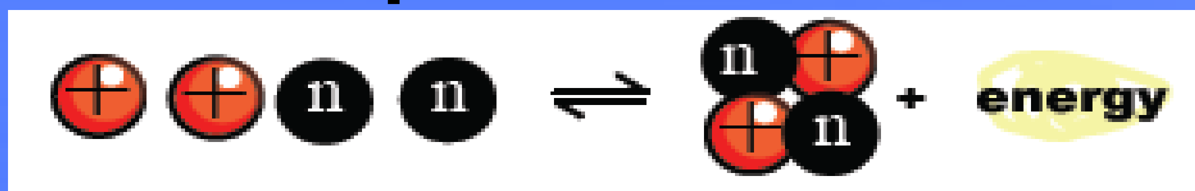
The extra mass must be stored as energy in the completed atom.

Binding Energy

- There is no difference in amount of matter when nucleons are held together in the nucleus.
- So what causes this extra mass?
- Scientists called this extra mass the **mass defect**
- Einstein's theory of relativity suggested that the missing mass is present in the strong nuclear energy holding the nucleus together. Nuclear energy must be very strong because it must overcome the repulsion forces present in the nucleus.
- This energy holding the nucleus together is called the **BINDING ENERGY.**

Binding Energy

- **This could be expressed mathematically using Einstein's energy/mass equivalence equation as:**



$$\Delta E = mc^2$$

where:
ΔE = binding energy (J)
m = mass defect (kg)
c = speed of light (m/s)

Examples

- Calculate the binding energy of deuterium.

$$^{2}_{1}H$$

- Mass of neutron = 1.67493 x 10^{-27} kg
- Mass of proton = 1.67262 x 10^{-27} kg
- Mass of deuterium nucleus = 3.34432 x 10^{-27} kg

Examples

- **The most abundant isotope of helium is helium-4, whose nucleus has a mass of 6.6447 x 10^{-27} kg.**
- **a) What is the mass defect of He-4?**
- **b) What is the binding energy of He-4?**
- **Note: Use more precise values of**
- **m_p = 1.6726 x 10^{-27} kg**
- **m_n = 1.6749 x 10^{-27} kg**